SSTO RLVs: MORE GLOBAL REACH?
A Study of the Use of Single Stage To Orbit Reusable Launch Vehicles as Airlift Platforms

GRADUATE RESEARCH PAPER

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AFIT/GMO/LAL/96N-13

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The views expressed in this graduate research paper are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

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GRADUATE RESEARCH PROJECT

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Maj John R. Stafford

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Abstract

The US military must think creatively to exploit potentially useful developing technologies in the pursuit of national security. Single Stage to Orbit (SSTO) Reusable Launch Vehicles (RLVs) are currently under cooperative development by NASA, the Air Force, and the aerospace industry in the pursuit of assured commercial and national access to space. The transportation elements of DoD (Air Mobility Command and USTRANSCOM) have the opportunity to exploit these rapid transit technologies to advance "Global Reach for America." The SSTO RLV is a single stage rocket that will be completely reusable, similar to an aircraft, yet deliver a C-130 size cargo anywhere on the planet in less than one hour. Industry, Air Force, and NASA sources were investigated to assess the projected capabilities and costs of the SSTO system.

This paper reviews the proposed capabilites of the SSTO system, discusses the current status of the development and test program, compares the proposed capabilities with current DoD and commercial transportation modes and costs, and recommends that Air Mobility Command, as airlift agent for USTRANSCOM and DoD as a whole, should pursue development and limited acquisition of SSTO RLVs for use as airlift platforms.

SSTO RLVs: MORE GLOBAL REACH?

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I. Introduction

"Time is everything; five minutes make the difference between victory and defeat."

Admiral Lord Nelson (Tsouras, 1992: 434)

"It is better to be in the right place with ten men than absent with ten thousand."

Tamerlane (Tsouras, 1992: 434)

Background

Air Mobility Command (AMC) is expending considerable effort to evaluate and develop the next generation of tanker aircraft and the replacement for the C-5. While both pursuits are in keeping with an extrapolation of our current defense needs into the future, they should also consider options "outside the box" or paradigm. Specifically, the US military must consider exploiting developing technologies that may offer aerospace craft capable of improving national capabilities, or even offering new capabilities. The Single Stage To Orbit (SSTO) Reusable Launch Vehicle (RLV) is such a craft. Global Reach proponents may attempt to dismiss SSTO RLVs as spaceships that belong to

United States Space Command (USSPACECOM) or the National Aeronautics and Space Administration (NASA). In an orbital role, replacing the Space Shuttle as the primary means of satellite launch and other space operations, they may be correct. But SSTO vehicles offer a suborbital as well as orbital surface-to-surface transportation option superior to the National Aerospace Plane (NASP) touted several years ago. When a shipper can place 11,340 kg of payload or passengers anywhere on the planet in one hour or less, and perhaps land on a parking lot instead of a 3000 meter runway, that is a significant capability.

Research into SSTO designs and reusable craft began with the early rocketry pioneers, who thought the ideal launch vehicle would consist of only one stage that discarded only propellant and used a lightweight structure and subsystems to minimize gross weight, size, and cost (Bekey, 1994b:32). However, technological development was not good enough at that point to produce such a vehicle. More recent emphasis began in 1982 when Boeing proposed a sled launched, winged SSTO orbiter to meet Strategic Air Command's requirement for placing a 9,070 kg payload in polar orbit. The original design, code named "Science Dawn" proved impractical, but Lockheed and McDonnell Douglas Aerospace (MDA) joined the project and improved the concept. The new project, called "Science Realm," encompassed vertical takeoff possibilities. In 1986, it split into two programs: NASP and "Have Region." The NASP continued the horizontal takeoff, horizontal land (HTHL) concept, while Have Region gave the rocket proponents a chance to examine new materials and structures for vertical takeoff, vertical

land (VTVL). Have Region ran until 1989, and along with its predecessors, cost a total of about $100 million (Dornheim, 1993:46).

In 1989 President George Bush, at the urging of the national Space Council, issued an updated US National Space Policy. That policy reaffirmed US leadership in space activities, the use of space to strengthen national security, and the encouragement of commercial use and exploitation of space (ACSC, 1995: vol. 5, 18-7 to 18-16). Toward this end, Bush's National Space Policy Directive identified the need to develop "a new space launch system to reduce cost and improve reliability and responsiveness" (Aldridge, 1993:241). Vice President Quayle assigned development of the project designs to the Strategic Defense Initiative Organization (SDIO), putting emphasis on reusable single stage vehicles (Port, 1993:119). In 1989, SDIO signed a $15 million contract with McDonnell Douglas to develop the reusable SSTO concept. MDA was awarded the contract based on recent experience in some classified reentry vehicle maneuver tests that demonstrated much of the technology required to maneuver an SSTO for reentry to a vertical landing (Dornheim, 1993:49).

The results of the study led to another contract competition, awarded again to McDonnell Douglas in 1991, to develop the first prototype SSTO reusable launch vehicle (Smiljanic et al, 1993: 2). That first vehicle, DC-X (Delta Clipper-Experimental) successfully completed the last of eight test flights on 7 July 1995. It was a one-third scale vehicle (approximately 13 meters tall and 4 meters in diameter at the base) designed to test basic vehicle design, maneuvering ideas, and supportability and maintainability

concepts. Once completed, the vehicle was refurbished with some added technological features, renamed the DC-XA, and a second phase of flight test conducted (Gaubatz, 1995: 3-5). The final flight concluded on 31 July 1996 after a fire on landing prevented the fifth test flight (MDA, 1996d: vii, 225).

The success of the DC-X prototype has shattered old paradigms concerning the mission profiles and roles for space-capable craft. Prior to 11 September 1993 (the first DC-X flight), rockets were expendable "ammunition"--good only for one flight (Stine, 1994: 65). The Space Shuttle had taken a small step toward reusability, but it's launch boosters were either expendable or had a long lead time for refurbishment. The Delta Clipper, VentureStar, and any other SSTO RLVs that develop will truly be reusable.

President Clinton's space policy upholds the development of technologies supporting a single stage to orbit vehicle (Asker, 1994: 24). In July 1996, the next step of development was taken when NASA signed a $1.16 billion contract with Lockheed Martin to develop a half-scale prototype under the program title X-33. Lockheed's VentureStar is designed to fly up to Mach 15 at altitudes up to 50 miles, and demonstrate most of the remaining technological advancements to achieve a fully functional SSTO RLV. The first flight of VentureStar is scheduled for March 1999 (Leary, 1996). One of those technological hurdles is the development of high technology "scramjet" engines loosely based upon NASP concept. Lockheed's aerospike engines will be the culmination of that research when they are produced (Cook, 1996c: WWWeb). Assuming a successful program, the full scale prototype is estimated to be complete by

2003, and commercial production and operation beginning in 2004 or 2005 (Gaubatz, undated-a:2-3). See Figure 1 SSTO Timetable below:

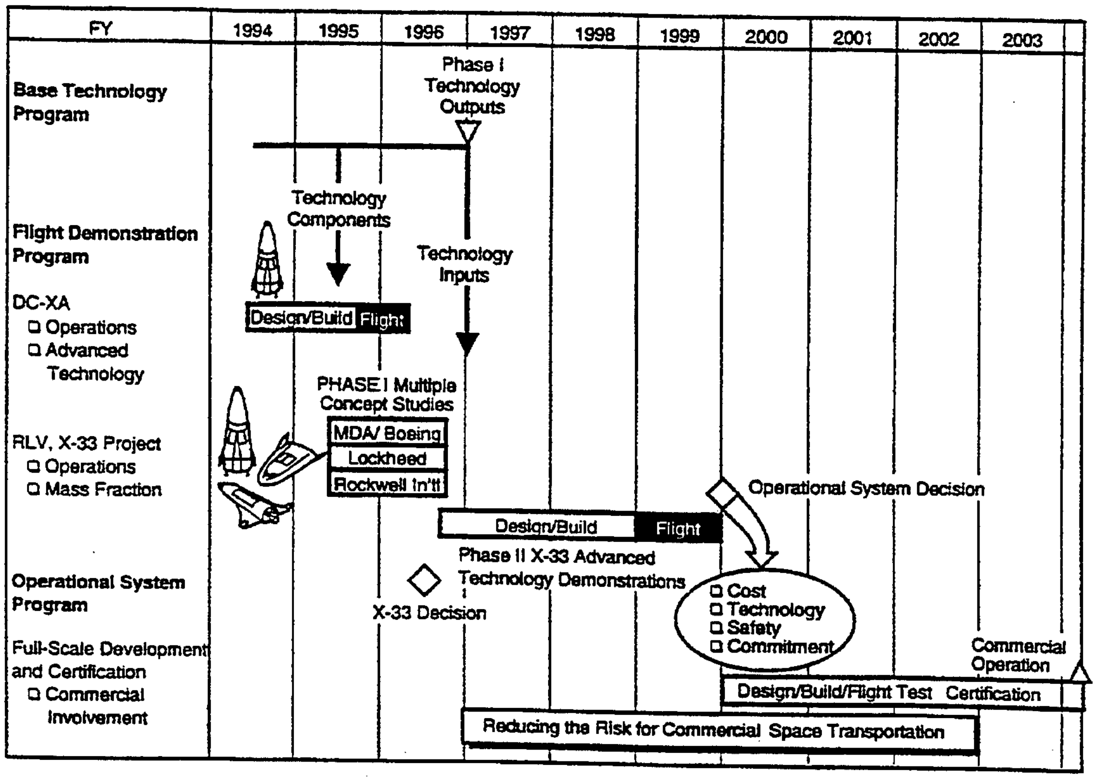

Figure 1. SSTO Timetable (Gaubatz, undated-a: 3)

The United States has relied heavily upon the Space Shuttle for its space launch needs during the last fourteen years. This system is so costly and manpower intensive that using it in a suborbital mode would be prohibitively expensive ($15-17,000/kg) (Ligon, 1996: 122). Nor is it reusable. Besides using expendable boosters, major portions of the vehicle and its fuel tanks are completely refurbished after each flight, hence the high cost. No new heavy lift vehicle designs have been developed since the arrival of the Shuttle, which is itself a twenty year old design. Consequently, the SSTO

RLV is the first practical system available to the Department of Defense (DoD) to perform in this fast and flexible transportation role. But to perform at an affordable and reliable level, an aircraft-like supportability and maintainability system must be implemented. Toward this end, Air Force Space Command (AFSPACECOM) said, "Airplane supportability experts need to be an integral part of the design and operations team" (BMDO, 1993).

Importance of Research

As mentioned previously, SSTO RLVs offer an expansion of Global Reach, providing additional capability to US national security assets. Whether used in the traditional airlift role, aeromedical evacuation, or as operational support aircraft (OSA), SSTO RLVs offer a number of advantages previously unavailable. Reusable SSTOs will very likely be developed to replace the Shuttle for delivery and retrieval of space assets. AMC should evaluate this technology for application to airlift. This paper will hopefully provide an introduction to SSTO RLV technology for those people who plan for future transportation assets in DoD. While current and projected US forces may meet all the threats of the future adequately, having a very fast, flexible delivery mode of transportation may mean the difference between success and failure.

The SSTO RLV offers a reusable vehicle to leverage the use of time. Whether current RLV programs are purchased, or other follow-on vehicles, the concept must be investigated and considered by our national military and civilian leaders if the US is to grasp this opportunity.

The commercial industries recognize the importance of time. The great Presidential emphasis on supporting development of SSTO is in recognition of the inability to meet the huge orbital and suborbital demands for launch capability desired by the commercial market (AFSPACECOM, 1994: 1-2). According to a Dr. William Gaubatz, McDonnell Douglas SSTO Program Manager, Boeing Corporation's aircraft parts supply branch and Federal Express are both very interested in the McDonnell Douglas SSTO concept. With a small fleet of reusable SSTO vehicles, Boeing could reduce its overseas parts distribution infrastructure, run the operation from Seattle, and save millions of dollars per year. In a similar vein, Federal express built their company around fast delivery at a premium price. An SSTO fleet would speed overseas shipments by an order of magnitude, offering even faster service. And if companies were to build large fleets similar to today's airline fleets, that would offer a significant pool for potential expansion of the Civil Reserve Air Fleet (CRAF) to the suborbital and orbital mode, further enhancing America's Global Reach.

The SSTO RLV is consistent with and enhances the current doctrinal use of airlift assets. The SSTO directly supports three of the four operational concepts in Joint Vision 2010: dominant maneuver, precision engagement, and focused logistics (Shalikashvili, 1996: 1, 20, 21, 24). Air Force Doctrine Document 30, Airlift Operations, states that:

> The power projection capability that airlift supplies is vital since it provides the *flexibility* to get rapid reaction forces to the point of crisis with *minimum delay.* Accordingly, airlift is viewed as the foundation of US national security at the strategic level.... Airlift also supports overall US national policy by projecting American power and influence in a wide range of non-lethal applications of airpower. (Department of the Air Force, 1995: 2) [Italics added]

Reusable SSTOs will enhance current airlift capability. They also improve on the AMC ability to meet the airlift objectives of force enablement, force enhancement, and national policy execution (see Figure 2 Airlift Objectives). Consequently, serious consideration of the advantages of SSTO RLVs is necessary and consistent with continuously improving America's Global Reach.

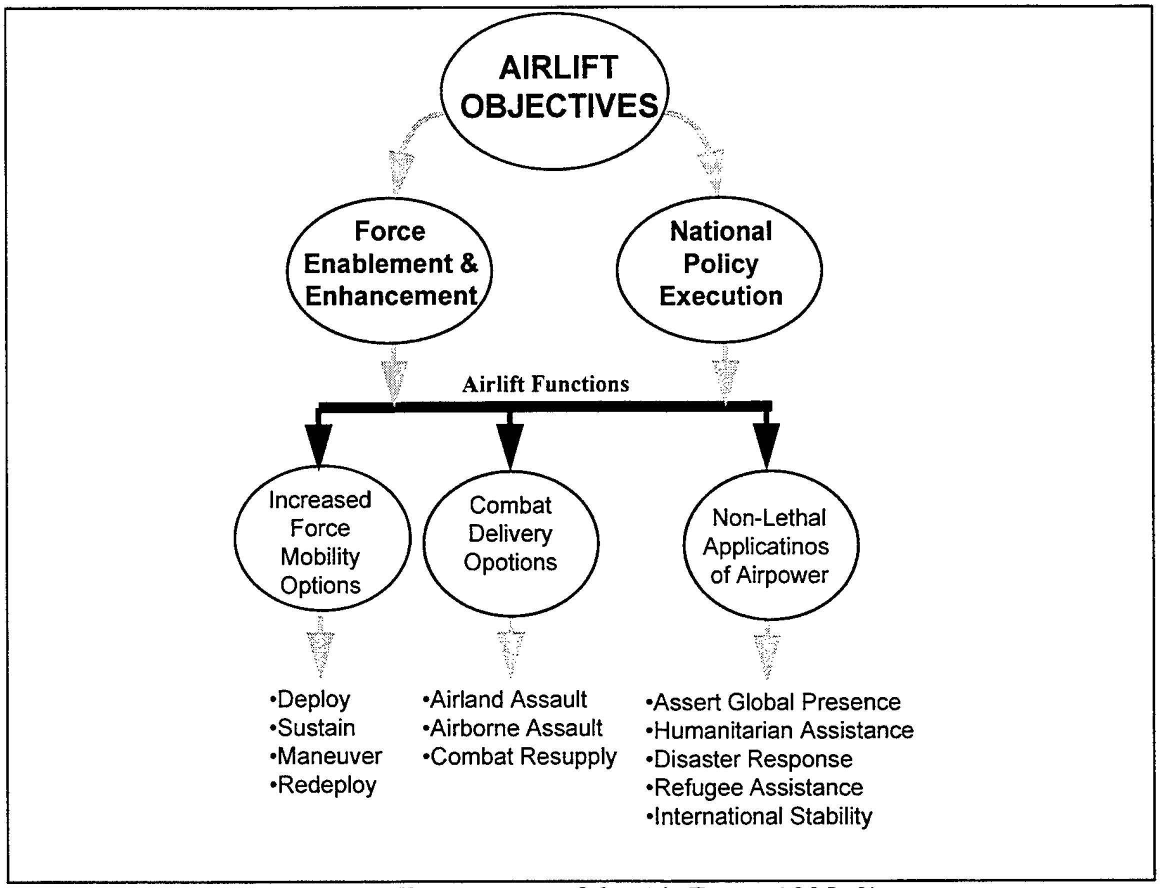

Figure 2. Airlift Objectives (Department of the Air Force, 1995: 3)

Problem Statement

Air Mobility Command, as airlift agent for the United States Transportation Command (USTRANSCOM) and DoD as a whole, must consider airlift options outside

their paradigm. Single stage to orbit RLVs provide a unique transportation opportunity which must be thoroughly investigated. Only after consideration can they know whether acquisition of such a rapid, flexible system would provide a suitable option to enhance national Global Reach capability. Consequently, this paper will determine whether it is feasible for AMC and USTRANSCOM to use an SSTO RLV as an airlift platform, and recommend a course of action.

Questions to be Resolved

This paper will explore the SSTO RLV concept--its past, present, and future. Through that discussion and analysis, several questions will be resolved to provide a basis for the feasibility decision, and prepare a platform from which further investigation can be launched by AMC, USTRANSCOM, or other transportation-minded leaders. *Is the SSTO RLV a viable technological concept?* The background section in this chapter has already discussed the confidence the President, NASA, and Air Force leaders have in this concept as shown by the continuing development of the SSTO concept. In addition, the subsequent chapters shall specifically describe how the reusable SSTO offers significant capability as an airlift platform. If so, *what capability would DoD acquire with the system?* These capabilities are projected since full scale prototypes are still some years off. *How much would this capability cost?* A service must know how much impact a program will have on its overall budget. Once a comparison is drawn between the capability and cost, then it can be compared to other modes to answer: *Is this system a good value compared to other modes of transportation?* Finally, a recommendation

based upon on the preceding questions must be made. *Should DoD develop and purchase this system?*

Overview of Research

Every nuance of developing and acquiring a new weapon system for AMC or DoD will not be developed here due to the limited scope of this paper. Even if the author wanted to, he does not possess the vast technical knowledge nor the programmatic expertise required to do so. Nor will the author discuss space-bound transportation. Both NASA and USSPACECOM have the relevant experience and structure to handle putting things into space. Rather, the paper will explore and justify a recommendation for further pursuit of SSTO RLVs as airlift platforms by Air Mobility Command, USTRANSCOM, and DoD. The focus will be upon a suborbital system for rapidly delivering people and cargo from one location on the earth to another. The paper may also serve as a starting point for those more skilled in these areas to pursue justification and acquisition of an SSTO RLV system.

II. Source and Information Overview

"In military operations, time is everything." The Duke of Wellington, 1800 (Tsouras, 1992: 434)

Introduction

When discussing any field of study, one must speak the language to understand the basic concepts. It is difficult to grasp the concepts involved without knowing and differentiating the specific terminology used for that particular field: the realm of space technology is no different. While many terms and acronyms will be used and explained throughout the text, Appendix A, Acronyms and Terminology summarizes them for ease of reference. These key words and concepts will lay the foundation for understanding the rest of the paper, and which may be useful to the reader who explores this topic further.

Since SSTO RLVs must fit into the current airlift structure, it is instructive to review current airlift doctrine. By doing so, the reader can ascertain that SSTOs can be easily integrated in the current airlift structure, and discover the ways in which such a vehicle can enhance those roles and missions. Some of those concepts are spelled out in this work. However, for those interested in further study, the CJCS Vision 2010, AF Doctrine Document (AFDD) 30, Airlift Operations, and AFM 1-1, Basic Aerospace Doctrine of the United States Air Force provide an excellent source of airlift doctrine. See the Bibliography for specific details.

Previous Work

An enormous body of research is available on the broader topics of space vehicles. SSTO is a more recent development stemming from research on the National Aerospace Plane (NASP) and the US Space Doctrine. No single book or article adequately defines the broad range of issues and developments in the SSTO and reusable space vehicle arena. However, the American Institute of Aeronautics and Astronautics (AIAA) publishes a regular series of articles covering the complete spectrum of this technological frontier.

Seven AIAA articles are quoted throughout this paper. All of them are presentations from a variety of international forums on space. Carter, Rachel, Corbin, and Block discuss the vehicle management system for SSTO vehicles in their paper AIAA 93-0963 (Carter et al, 1993). Items of discussion include vehicle systems requirements, commonality of hardware and software, software specifics for flight control and system management, guidance and navigation, crew module interfaces, communications, supportability, and the integration of these subsystems.

For propulsion systems, Fanciullo and Judd present detailed descriptions of the engine's reaction control system in AIAA 92-0964 (Franciullo and Judd, 1993). Holloway and Limerick discuss engine performance requirements, operability, engine configuration, and the challenges of reusability in AIAA 93-0966 (Holloway and Limerick, 1993). In AIAA 95-3609, Goracke and Levack discuss the various tri-propellant engine and fuel options for SSTOs (Goracke and Levack, 1995).

SSTO supportability and ground servicing are covered in AIAA 93-0962 and 93-0965 respectively. Smiljanic et al write at length about the design of the Delta Clipper and their attempt to design an aircraft-like maintenance and support regime around it rather than an expensive and unresponsive rocket support system (Smiljanic et al, 1993). Rozycki and his three co-authors discuss the ground servicing fluid system design for the Delta Clipper to handle liquid oxygen (LOX) and liquid hydrogen (LH2) (Rozycki et al, 1993).

Finally, Dr. William Gaubatz and several others from McDonnell Douglas and the Ballistic Missile Defense Office (BMDO) discuss the development of the first Delta Clipper vehicle, DC-X, in AIAA 93-4163. Sections include the overall concept and background, followed by the technologies being demonstrated, the operations and support concept, design process, aerodynamics, avionics, vehicle management system, software, and propulsion (Gaubatz et al, 1993).

In addition to AIAA sources, much information has been published by industry sources concerning SSTO RLV systems. McDonnell Douglas Aerospace has published a number of articles and reports concerning its Delta Clipper design and its prototypes, the DC-X and DC-XA. The most informative and comprehensive of the group are the final test results from the DC-XA, available from McDonnell Douglas as document tracking number SSRT-96-XA01 through XA04 (MDA, 1996). Such articles and reports provide detailed information concerning prototype standards and performance, special problems encountered, detailed test data, photos, and other useful information.

The government has performed several studies of space transportation related topics including the studies mentioned in Chapter 1. In addition, AFSPACECOM developed a Technical Requirements Document (TRD) for the McDonnell Douglas SSTO system in 1993 (AFSPACECOM, 1993). They also wrote the Military Aerospace Vehicle Operational Requirements Document (ORD) in 1994 (AFSPACECOM, 1994). Both these documents provide the basis for development of the SSTO RLVs. They define the government requirements, and minimum performance standards in considerable detail.

Several cost studies have also been performed. Aerospace Corporation performed a cost analysis for development of an SSTO system in September 1993 at the request of BMDO, the Space and Missile Center, and AFSPACECOM (Hovden et al, 1993). This study was very useful and provided a significant amount of the "government" costs used in this paper. The other significant cost statistics contributor was an AFSPACECOM cost summary for SSTO operational capability completed in November 1993 (AFSPACECOM, 1993b). Nearly all government costs cited come from these two sources. Applied Research, Inc. performed a cost estimate for Phase II of the SSTO development program (contract given to Lockheed Martin in July 1996) in October 1993 (Tucker and Panciocco, 1993). This estimate served as a benchmark to compare the VentureStar system against, especially since detailed cost figures were unavailable from Lockheed Martin.

For comparative data on aircraft, the Air Mobility Command Data Book, May 1996 edition, provides excellent cost, range, and payload information (Office, 1996). Additional information can be sought through the office of primary responsibility, HQ AMC/QI.

Detailed information about US national space policy can be found in the National Space Policy Directives. They have been published by both President Clinton and President Bush. Also, the Air Command and Staff College (ACSC) texts include a good overview of US national space policy and specific applications (Air University, 1995:18-7 to 18-16). Specifically, the ACSC texts provide detailed accounts of Presidential and national interest in a variety of space applications. Most of it is not applicable directly to SSTOs, but an encompassing drive for cheaper and more reliable access to space is very prominent.

For information concerning the production, handling, storage, and purchase of cryogenic fuels, John Walsh at BOC Gases provided immense help (Walsh, 1996). As an international producer and supplier of a variety of gases, BOC offered information concerning all aspects of gases as they would relate to potential SSTO operation. As for military handling of cryogenic gases, Staff Sergeant Peterson and Sergeant Novak at the McGuire AFB POL Plant offered descriptions of current capabilities. Sergeant Cassidy, at the McGuire AFB Fuels Accounting office, provided information concerning costs for fuels under Air Force contracts (Peterson et al, 1996).

As the launch date of the VentureStar nears (March 1999), more information will become available on the Lockheed Martin craft and its eventual follow-on production model. In addition, the government will need to select a contractor to replace the Space Shuttle with its SSTO RLV. The commercial launch market will undoubtedly also be pressing companies to produce a viable RLV to improve cheap access to space. As the technology comes to fruition, more sources of information will blossom. But a fundamental understanding of the SSTO RLV capabilities is available now in print, and should be sought by those responsible for promoting Global Reach for America.

III. Discussion of the SSTO RLV Development

> *"Speed is the essence of war. Take advantage of the enemy's unpreparedness; travel by the unexpected routes and strike him where he has no precautions." Sun Tzu*
>
> (Tsouras, 1992: 434)

Overview

The last three Presidents of the United States have made easier, cheaper access to space a priority. In July 1996, NASA embarked on a prototype program (X-33) with Lockheed Martin costing in excess of $1 billion to fulfill this national need. But a reusable SSTO is not only important to the US as a commercial asset and a national space access asset, but also as a potential means of rapid, flexible transportation for DoD. Industry and NASA are already developing the technology, and it will likely be fielded by NASA and industry. Air Force Space Command is also considering an SSTO RLV not only as a replacement for the shuttle, but as a direct force application platform. Because of this probably inevitable development, AMC should, as the airlift agent for USTRANSCOM and DoD, thoroughly investigate this mode of transportation to assess its potential contribution to Global Reach for America. The SSTO technology offers very fast transportation, flexibility, and potentially another CRAF avenue for AMC to exploit in its continuing pursuit of providing transportation to other DoD customers. This paper only touches the surface of many issues, and recommends further study to ensure AMC's understanding of this new technology.

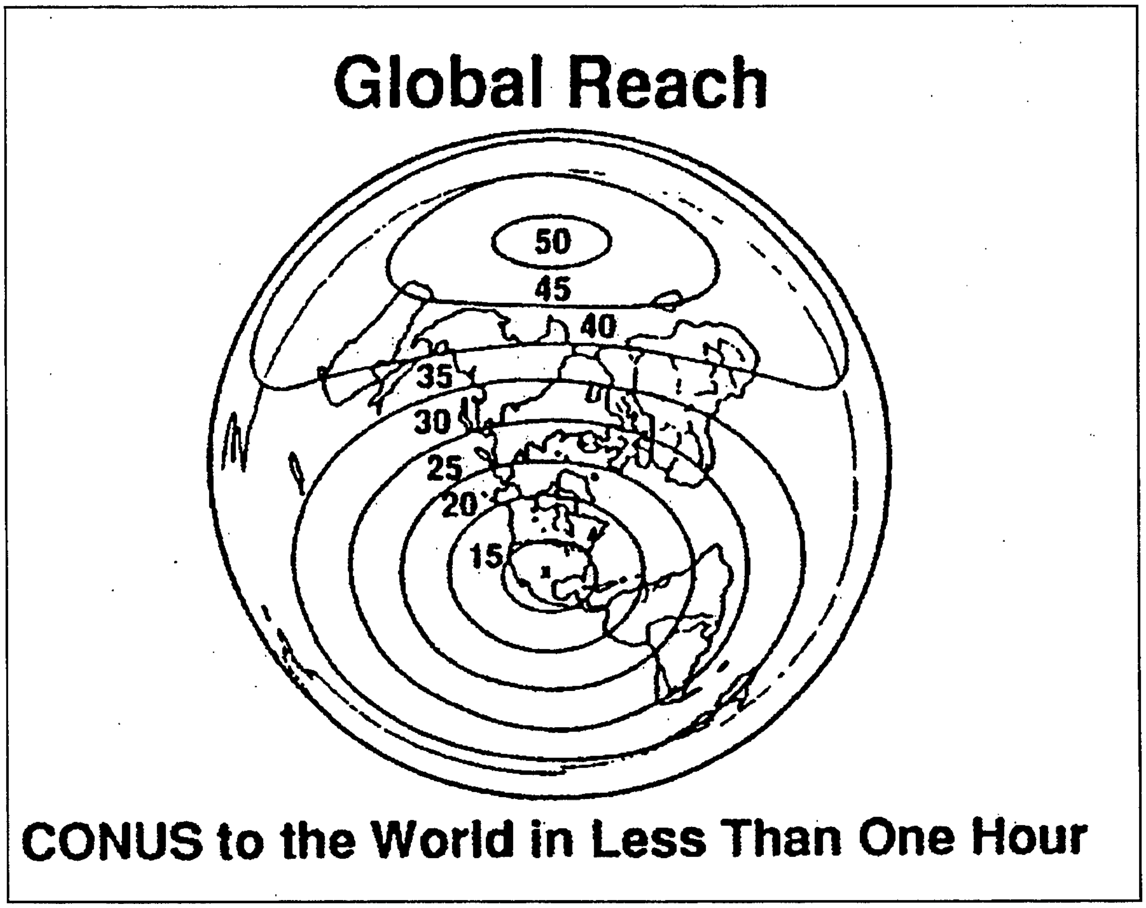

Figure 3. Global Coverage of SSTO (AFSPACECOM, 1993b: 15)

What does an SSTO RLV bring to USTRANSCOM and AMC? As mentioned earlier, this paper will not address space-bound transportation. Rather, the reusable launch vehicle would be best suited for AMC use in the suborbital role. A suborbital mission would takeoff from one location, fly rapidly up into the upper atmosphere short of low earth orbit (300 miles), and descend to land and deposit its payload. In this role, it would operate much as an aircraft, with refueling, uploading and downloading, and minimal servicing when necessary. The delivery time would be less than one hour to

Table 1. SSTO Comparisons (multiple sources)

	Delta Clipper[1]	VentureStar	Shuttle
Height	42 m	39 m	56 m
Vehicle Dry Weight	47,200 kg	118,000 kg	72,600 kg
Takeoff Gross Wt.	590,000 kg	1,043,000 kg	2,041,000 kg
Cargo Volume	4.6m X 4.6m X 9.1m	4.6m X 4.6m X 13.7m	4.6m X 4.6m X 18.3m
Payload	11,340 kg	27,200 kg	14,500 kg
Takeoff Mode	Vertical	Vertical	Vertical
Landing Mode	Vertical-Powered	Horizontal-Glide	Horizontal-Glide
Runway Req't	137m X 137m	2400-3000m	4570m
Fuel Type	LOX, LH2, JP-4 option	LOX, LH2	LOX, LH2, Hydrazine
Crew	Optional	Optional	Required
Turnaround Time	7 days normal, 2/day emergency	7 days normal, 2/day emergency	≈ 6 months
Cost/Launch	\$8.8 million	\$10 million	≈ \$500 million
Cost/Kg[2]	\$776/kg	\$368/kg	\$34,000/kg
Time to Farthest Pt	≈ 50 minutes	72 minutes	N/A[3]

Note 1: McDonnell Douglas figures.
Note 2: Based on figures above. Delta Clipper and VentureStar numbers do not reflect overhead and R&D which will push these numbers up to about \$1100-2200/kg.
Note 3: Not available. However, the Shuttle is restricted to two primary bases, and a small number of emergency alternates. Flight time should be similar to the VentureStar.

Proposed SSTO RLV Capabilities

As mentioned earlier, whether used in the traditional airlift role, aeromedical evacuation, or as operational support aircraft (OSA), SSTO RLVs offer a number of advantages previously unavailable. Some of these capabilities are summarized in Table 1 above. As an aeromedical airlifter, a critical load of patients could be delivered from the theater to a stateside hospital in 20-40 minutes--perhaps even landing in the parking lot on the helipad. Or if the theater commander needed to go to Washington, DC to brief Congress or his chain of command, he or she could be there in 20-40 minutes instead of 10 or more hours. Of course, in the traditional airlift role, nearly all the goals and objectives of airlift (see Figure 1 from AF Doctrine Document 30) that support force enablement, force enhancement, or direct national policy execution are attainable through reusable SSTOs.

Many of the SSTO RLV features have been highlighted already. However, the proposed capabilities vary somewhat by vehicle. Also, there is some variation between what the Technical Requirements Document and the Operational Requirements Document call for, and what industry projects the vehicles will do.

The Technical Requirements Document (TRD) for the S-3 Spaceplane SSTO System, completed 15 April 1993, was written with the McDonnell Douglas full size SSTO RLV in mind (AFSPACECOM, 1993a). It defines a number of desired performance areas for the entire SSTO system, including servicing and ground support. In the design reference missions, operations similar to current Space Shuttle missions are

described: deploying space assets, recovery of space assets, space rescue, etc. These are summarized in Appendix C of the TRD. Initial operating sites were traditional space launch and recovery sites of the Space Launch System (SLS). The SSTO must be capable of a number of specific tasks, including self-ferry to or from a remote landing site. It must be capable of turnaround in 7 days or less, with an emergency turnaround of 12 hours. It should have an availability rate of 95 percent independent of weather conditions. It shall be able to launch from either coast of the US, or central US without undue danger to persons or property [TRD Section 2.1].

The TRD requires the vehicle itself to be single-stage, reusable, and self-powered. It must be capable of delivering a 4536 kg payload (excluding payload container) into a 186 kilometer circular orbit and returning safely. The SSTO must carry sufficient fuel onboard to allow a 183 meters per second (mps) maneuvering velocity change in orbit, with a possibility of up to 366 mps. The vehicle must be capable of reorienting itself in space to within one degree of the desired direction. It must be designed to last for a minimum of 500 flights over a 20 year lifespan, with engines lasting for 200 flights without replacement. The safety rate for the operational system must be 0.99999. Its cargo must be containerized in a stand-alone container with standard hookups to the aerospace vehicle to facilitate ground handling. The standard container shall have an internal volume of 4.6 meters wide, 4.6 meters high, and 9.1 meters long and weigh no more than 453 kg. The cargo must be loaded on the payload container at an off site location prior to loading on the RLV. Payload must be capable of being monitored by

capable of crewed and uncrewed operation. A sub-sonic emergency crew egress system must be installed if crew are used. The crew must also have windows for outside visibility. Remote flight may use video for outside visibility [TRD Section 2.2].

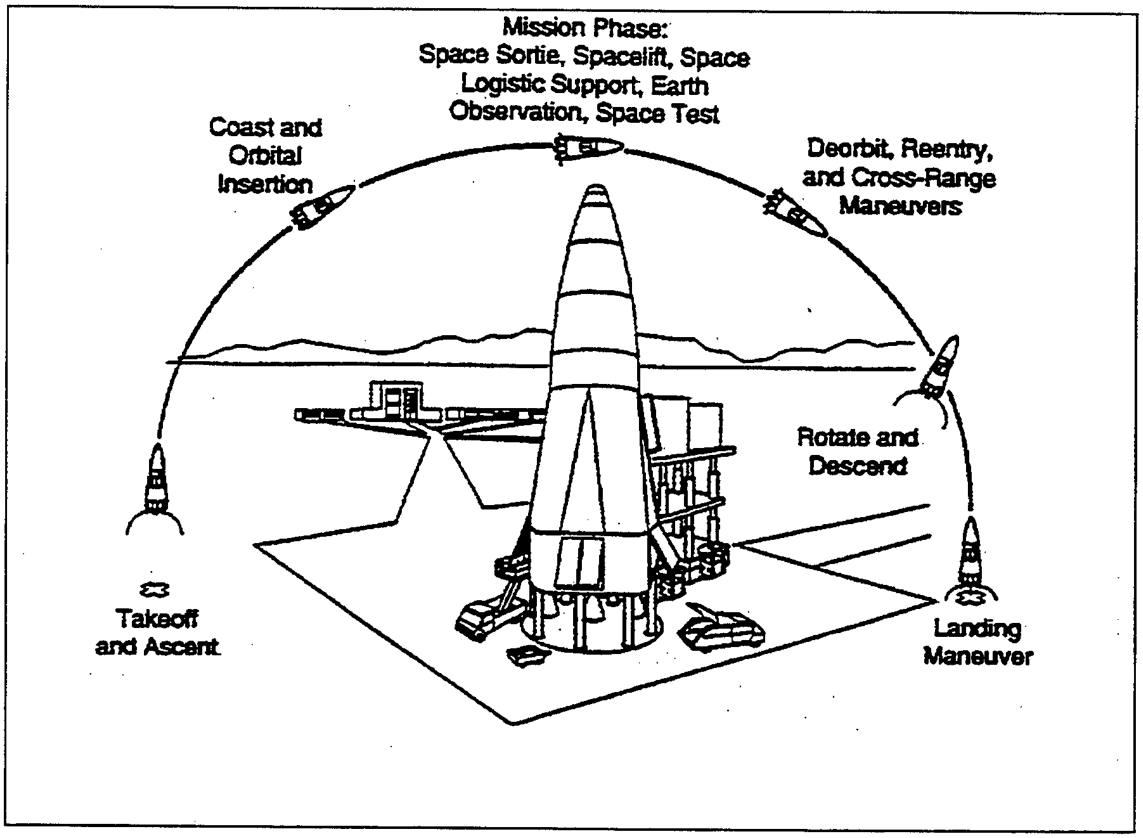

Figure 4. Delta Clipper Operational System (Gaubatz, undated-b: 5)

For ground operations and interface, the TRD specifies that the vehicle must be capable of being towed when unrefueled. It must also have standard UHF, VHF, HF, SATCOM, and space operations related radio and data equipment. The NAVSTAR/GPS system must be installed and integrated into the navigation computer and autopilot. The vehicle shall be capable of flight with no more than 350 man-days of servicing and

maintenance between flights. All repair and servicing equipment must be air transportable to any emergency or non-operations landing site on existing transport aircraft [TRD Sections 2.2 and 2.3].

The Operational Requirements Document (ORD) for the Military Aerospace Vehicle (MAV) Flight System was completed by AFSPACECOM in 1994 (AFSPACECOM, 1994). It's content is similar to the TRD, but much more detailed. Only significant items in addition to the TRD requirements or changing those requirement will be mentioned. The ORD includes some very interesting ideas and capabilities for AMC. In its mission area description, the ORD highlights the idea that SSTOs may be sold to commercial enterprises in large numbers. If so, since they may be a source of expansion of the CRAF, the military SSTOs must be compatible with the civilian models. Mission needs include the ability to operate in orbital and suborbital space, as well as to low earth orbit (LEO) and an geosynchronous transfer orbit [ORD Sections 1.1 and 1.2].

For launch sites, design and operation will not be limited to current launch sites. The remote flight and repair requirements of the TRD are repeated. The vehicles must be capable of certification for flight by the Federal Aviation Administration (FAA). Ground servicing and maintenance will be performed like modern military and commercial aircraft, with minimal servicing times and flight operations routine. The ground systems and flight vehicle must be operable and maintainable by Air Force military personnel with little or no direct contractor support. Logistic support will follow standard Air Force

logistic channels and practices. There is an integrated Logistics Support attachment to the ORD. Launch pad servicing will be done through removable umbilicals attached to portable servicing vehicles (or potentially in-ground systems). A portable hangar which serves as aircraft shelter and depot maintenance hangar will be used [ORD Sections 1.3, 1.4, and 3.7].

The vehicle must be capable of all-weather, night or day operations down to FAA Category 3 approach minimums. It must launch or land in 25 knots of wind, with gusts up to 35 knots. A surge equivalent to double the routine launch rate must be sustainable for 30 days minimum. The payload requirement was increased from 4500 kg to 9000 kg. In the event of non-catastrophic failure, especially in the engine, the vehicle must be able to abort intact to the launch site immediately or after one orbit. It must also be able to complete the entire mission with one airborne engine failure. Flight control must be accurate enough to touchdown consistently in a 61 m diameter area. The SSTO must have capability for a crew of two to maintain orbit for two days (four days in emergencies). Containerized additional life support will be used for additional personnel or passengers [ORD Section 4.1].

The maintenance and servicing workers will not be required to exceed high school plus two years of technical training. They shall be able to generate a sortie on demand in an amount of time similar to other modern military aircraft, with routine flight servicing not to exceed 24 hours. The launch on need (LON) shall not exceed 72 hours, with a goal of 24 hours. The vehicles shall have a 95 percent reliability launch rate within 24 hours.

All maintenance jobs, including engine replacement, shall be finished in seven days or less, with a goal of three days. Flight safety shall demonstrate a minimum of .999 with a goal of aircraft reliability of .999995. Fault detection and isolation must be 100 percent on all primary systems, with isolation to a line replaceable unit (LRU) at least 90 percent of the time. Automated fault detection overall must be 100 percent. In-orbit servicing and maintenance must be possible. Ground servicing must be possible from the ground or standard servicing platforms. Ground support equipment (GSE) shall be standard Air Force equipment to the maximum extent possible. Additional GSE shall be contractor provided. Off site maintenance support shall be provided through Air Force Material Command [ORD Sections 4.2, 4.3, and 4.7.1].

The ORD calls for fuels management to be performed in accordance with Air Force Manual 67-1, Volume 1, Part Three, Chapter 4. These propellants will likely be liquid oxygen (LOX), liquid hydrogen (LH2), and potentially some form of kerosene (possibly JP-4) if a tri-propellant engine is used [ORD Section 4.3.8].

The contractor shall develop the initial familiarization and training programs for Air Force and/or contract personnel. The programs will develop training to the Air Force 5-7 level, with trainees at the 3 level. This training shall include overall space mission awareness, as well as particular technical duties. Once trained, operations of flight and preflight shall not need more than three individuals, with no more than 30 support personnel for preventive maintenance and repair [ORD Section 4.7.3].

The manufacturers have taken the requirements and begun to develop their craft accordingly. However, in many cases, the capabilities they project for their vehicles exceed the requirements. Also, many specifics are not defined in the requirements at all, and so, will be listed accordingly. See Table 1 for a summary of many pertinent characteristics, especially height and weight of the vehicles.

The full scale VentureStar aims for a safety record at least 10 times safer than the Space Shuttle, which is one failure in 145 flights. VentureStar's and Delta Clipper's cost goal is \$2200/kg or less, compared to the Shuttle's nearly \$22,000/kilogram (Leary, 1996: A1). VentureStar is a wedge-shaped lifting body (see Figure 5) as compared to the conical Delta Clipper design, while the Shuttle has characteristics of both the lifting body and aircraft-style design. Both the Shuttle-style SSTO and the VentureStar will takeoff vertically, fly nose-first to destination, and land horizontally as a glider (unpowered) similar to current Shuttle operation. None of the three proposed SSTO designs would exert more than 3 g's of force on the cargo/passengers, and this only during takeoff (Gaubatz et al, 1993: 2) and (Baumgartner).

Using government requirement figures, the full scale Delta Clipper (S-3 or DC-1) would offer a 4.6m X 4.6m X 9.1m cargo bay and carry 9,100 kg of cargo (AFSPACECOM, 1993b). Cost estimates are about \$970/kg using costs in Table 2 (Chapter 4). McDonnell Douglas estimates the Delta Clipper can carry 3000 more kilograms of cargo than required, lowering the cost/kg to \$776. The flight profile is to takeoff vertically as the other two designs, however after reentry, rotate to put the engines

toward the ground and use thrust for braking and landing (Gaubatz et al, 1994b: 2). Hover is possible, also.

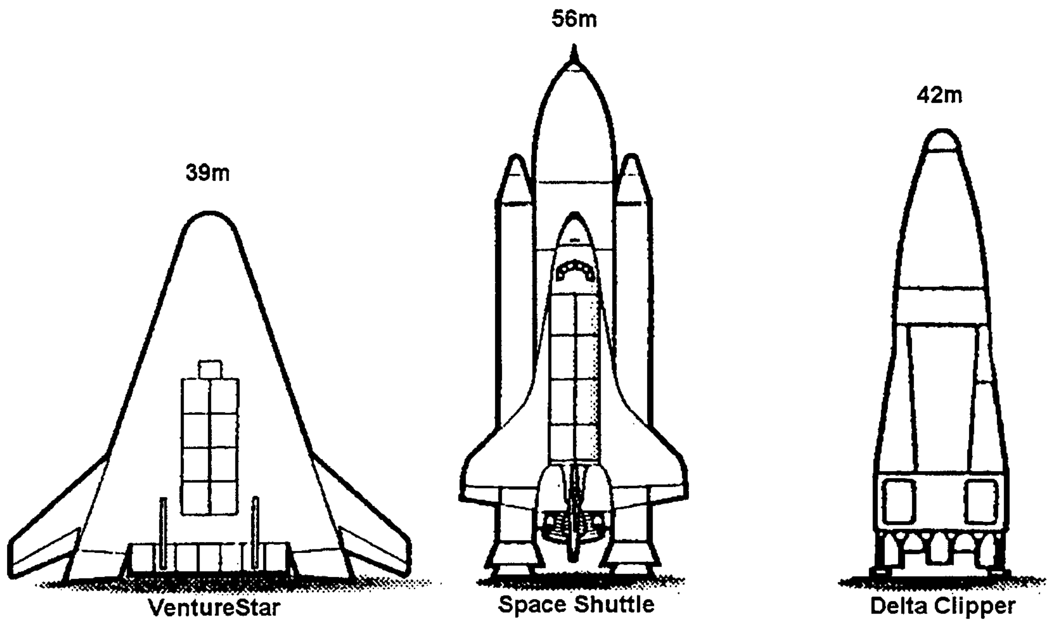

Figure 5. SSTO Vehicles

As a ballistic vehicle, the Delta Clipper would also use atmospheric friction to slow its reentry. The unique shape of the Delta Clipper enables it to maneuver during reentry with small aerodynamic controls (extendible flaps). These controls do not add any appreciable drag to the vehicle when retracted, and they eliminate the significant additional propellant required to lift wings. (Port, 1993: 119).

The simpler shape of the Delta Clipper allows for the use of less complex thermal protection systems. The Shuttle is a complex shape that has 17,000 uniquely shaped thermal protection tiles (Nordwall, 1994) that collectively weigh almost 8600 kg (Rockwell, 1980). The hot spots which develop during reentry along the leading edge of

the wing require even higher protection levels than the rest of the vehicle. Any winged vehicle (VentureStar or Shuttle) would inherently have similar thermal protection requirements. The Delta Clipper's simple geometry requires just a few common tile shapes and should consequently cost significantly less to build and maintain than a winged vessel (Port, 1993).

The Delta Clipper would employ 8 liquid oxygen (LOX) and liquid hydrogen (LH2) burning engines. Of these 8 engines, 4 would be fitted with low altitude booster nozzles, and 4 with high altitude sustainer nozzles, producing an average 97,000 kg of thrust and 348 seconds of specific impulse at sea level and increasing in space (Holloway and Limerick, 1993: 6-7). This translates into approximately a 1.3 thrust-to-weight ratio at liftoff and much higher at landing (Gaubatz et al, 1993: 2). Another option being investigated is an engine that changes the shape of the exhaust nozzle, such as those on the submarine launched Trident missiles (Semi-, 1996: WWWeb). VentureStar, on the other hand, will use the aerospike engines currently being developed. They are also LOX and LH2 fueled, with a water coolant (Cook, 1996c: WWWeb).

Tri-propellant engines are another alternative, initially burning kerosene (similar to JP-4 jet fuel) and LOX, then switch to LOX-LH2 in later stages of flight. Theoretically, tri-propellant engines could attain SSTO mass fractions in excess of 0.90 (Bekey, 1994b). These engines produce more thrust, but less efficiency initially by burning a mixture of kerosene, hydrogen and oxygen. Later, the engines switch to hydrogen-oxygen when the launch vehicle's lighter weight allows for reduced thrust. The

tri-propellant system improves overall system efficiency by employing high thrust, lower efficiency modes when necessary. Bekey calculates that tri-propellant technology engines alone could drive mass fractions over 0.90 (Bekey, 1994b). However, another study by Rocketdyne in 1995 found that bi- and tri-propellant engines resulted in nearly identical vehicle performance (Goracke and Levack, 1995: 1).

Bi-propellant (LOX/LH2) engines are much more environmentally friendly than kerosene burning engines. The exhaust product of the LOX/LH2 engines is water. Combining this clean exhaust with the lack of debris (single stage) and manageable noise levels makes SSTOs very environmentally friendly (Worden and Sponable) and (Worden et al, 1993: 23).

The reason rocket engines are being tested for SSTO is that air breathing engines are not efficient enough. The best military jet engine produces a thrust to weight ratio of about 8:1. The Shuttle main engines each produce about 70:1. An SSTO engine will be even more efficient (Semi-, 1996: WWWeb).

Gaseous hydrogen and gaseous oxygen would be used for reaction control engines to make fine-tuning attitude adjustments (Gaubatz et al, 1993: 2). The gaseous O2/H2 propellant system provides a synergistic effect to LOX/LH2 powered engines in both initial starts, restarts in flight, and reduced logistics due to easy conversion of liquid to gas (Fanciullo and Judd, 1993). Gaseous helium is used to prevent geysering of the LOX (Rozycki et al, 1993:1). Gaseous nitrogen is used to purge the fuel system lines (Baumgartner).

The Space Shuttle uses LOX/LH2 for its main engines and solid fueled boosters, nitrogen tetroxide oxidant, monomethyl- hydrazine fuel (highly toxic and corrosive), and helium pressurant for its orbital maneuver engines and reaction control thrusters. It uses mono-propellant hydrazine fuel (highly toxic and corrosive), cooling water, and nitrogen pressurant for hydraulic power generators, and a separate hydrogen-oxygen system for electrical power generation (Rockwell, 1980). Delta Clipper and VentureStar will use electromechanical controls to eliminate the requirement for any hydraulic system at all.

The DC-X used off the shelf aircraft components. The designers plan to continue to use aircraft-style avionics in the later models. One of the prime supportability features of the Delta Clipper vehicles and other SSTOs in the works is their extensive use of off the shelf systems to maintain high reliability. An estimated 2000-5000 hours mean-time-between failure should be realized on all electrical components, in addition to multiple redundant systems in the event of failure (Carter et al, 1993: 3). On board diagnostics and control systems similar to commercial airliners will also be included. Similar systems are expected on VentureStar. Through this use of proven off-the-shelf hardware, the RLV designers eliminate the need for expensive reliability qualification testing and acceptance (Smiljanic et al, 1993a). Most of the Delta Clipper's modular avionics are "line replaceable units" or "LRUs" that can be quickly fault isolated and replaced by technicians. The onboard avionics system should fault isolate no less than 70% of all the LRUs. This will help cut turnaround time and expense since LRUs receive off-site

servicing. Furthermore, an average aircraft mechanic (3-5 level blue suit maintenance) could do the work with little additional training (Smiljanic et al, 1993a: 27).

The Delta Clipper Flight Operations Control Center (FOCC) is designed with standard personal computer workstations and modified commercial software that enables three people to control all ground and flight operations (Worden et al., 1993: 22). With computer data links, monitoring of launch and flight status could be made from the AMC/Tanker Airlift Control Center (TACC).

Using graphite-composites, aluminum-lithium and other lightweight materials in the design of an SSTO could reduce dry vehicle weight enough to raise the mass fraction to over .89 with current non-tri-propellant engine technology. Lighter components require lighter mounts, structures, and supporting systems, and so every kilogram saved results in more than one kilogram total weight savings for the system. As an example:

> Substituting Al-Li for aluminum in both propellant tanks results in about a 4% direct weight savings. But this substitution also enables the supporting structure to be lighter, the wings smaller, the propellant load lighter, and the engine's thrust lower. The net result is a 23 percent vehicle weight reduction. (Bekey, 1994b:34)

Such a savings was confirmed on the DC-XA. When McDonnell Douglas replaced the aluminum LOX tank with the Al-Li composite, it reduced the weight by 544 kg (Cook, 1996a: WWWeb) on a vehicle that only weighed 14,000 kg fully loaded, for a 3.8 percent savings (MDA, 1996a: 13) However, the test vehicles have thus far not shown the fully lightweight (80 percent lighter than current) construction needed for an SSTO vehicle (Dornheim, 1995: 56).

The Delta Clipper requires a much smaller support staff than the Space Shuttle. The four NASA shuttles require 6,000 support workers, and prepping each Shuttle for flight costs about $500 million and up to a million man-hours over many weeks (Port, 1993). Support for the Delta Clipper is much simpler because the systems are simpler, there is no stage stacking, and the system uses aircraft style servicing procedures. Servicing and refurbishment should take less than a week between flights and 350 man-days. According to Worden et al, a ground crew of 20-40 people could maintain and turn the Delta Clipper around between flights (Worden et al, 1993: 23). The launch staff consists of three people and two pilots, either remote or in the craft. The Delta Clipper could even fly twice in one day if the crew pushed (Port, 1993). The annual maintenance inspection would take the vehicle out of service for 30 days. The SSTO system is designed to operate as two-level maintenance, with line replaceable units (LRUs) pulled and replaced with new ones rather than repairing them on the vehicle. Pulled LRUs would be sent to depot level repair at the appropriate location. Air Force skill levels would be 3-5 level, and no more than 10 skill specialties would be required (Smiljanic et al, 1993: 26-7). Lockheed Martin estimates a ground crew of 150, with 38 needed to turn the VentureStar around for a second flight (Baumgartner).

The Delta Clipper, having a powered descent, can vary its destination by up to 1200 miles from the plane of orbit (Carter et al, 1993: 2). Any SSTO should have similar capability, though unpowered descending vehicles will have less flexibility at lower altitudes. The powered lander can abort more safely in any phase of flight, and is less

bothered by crosswinds. A drawback to the VentureStar design is that, being a VTHL, it cannot return to its launch site if an abort after takeoff is required. It must fly to a runway for landing (Sponable). The launch/recovery pad for the VTVL must be 137m by 137m (Gaubatz), while the VentureStar needs an 2400-3000 meter runway. The Lockheed craft is limited to 20 knots of crosswind also, versus the 35 knots for the Delta Clipper.

The primary market Lockheed Martin is aiming for is the commercial space market, not a surface-to-surface suborbital use (Baumgartner). While this is also true of the Delta Clipper, the MDA team has considered other options for military use, including suborbital RLVs (Gaubatz). McDonnell Douglas has proposed several variations on the basic Delta Clipper model. This "Family of Vehicles" ranges from a suborbital-only model carrying 1361 kg, to a tri-propellant driven model with a 4.6m X 4.6m X 18.3m cargo bay capable of carrying 34,000 kg (MDA, 1993: 10-14).

To use the SSTOs effectively, they will have to be certified for flight by the FAA like civil aircraft. Otherwise, the cost of range control and other NASA-like single launch certifications will drive costs up prohibitively. Toward that end, top level discussions were held in late May 1995 between the NASA RLV program managers and the FAA (Zapata, 1996: WWWeb). In addition, AMC will have to train its airspace controllers in operations above Positive Control Airspace (Flight Level 600).

Current Program Development Status

The SSTO program has developed very quickly compared to other recent space projects. The first flight of the DC-X came only 24 months after contract award. The streamlined partnership between government and industry during this development is the direct cause of such rapid advancement (Gaubatz and Sponable, 1994: 6). One of the objectives of the SSTO program is to achieve the lowest life cycle costs. According to NASA, this will be achieved by:

> ...developing technology before proceeding with system development; bringing the needed technologies to maturity and demonstrating them through flights of an experimental rocket; demonstrating and validating vehicle design via flights of a full-scale prototype, with gradual stretching of the flight envelope; one-time certification of the vehicle design; and type-certification of the fleet. (Bekey et al, 1994a: 41)

In other words, NASA says to build rockets the same way X-aircraft are currently built. That is, most of its technology has already been matured in other programs, and its development involves progressively larger prototypes that minimize the overall risks associated with a system failure. The original DC-X is proof the process works, being built successfully for less than $67 million dollars--very little money in aerospace terms (Dornheim, 1993: 49).

Since off the shelf technology is the goal, the DC-X and DC-XA were built from scrap parts and other available materials. They used four Pratt and Whitney RL10-5A rocket engines from a Centaur rocket, an F-15 inertial navigation system, an F-18 accelerometer and rate gyro, an MD-11 autopilot and avionics, and a Honeywell GPS (Stine, 1994: 66-7).

Testing of the DC-X validated aerodynamic control of the vehicle during all phases of flight, including hover and autoland. Throttled rocket propulsion control was also validated, as well as autonomous flight by the vehicle (no ground inputs) (Gaubatz et al, 1994a: 1-3). The program demonstrated the required ground support equipment, minimal ground operations and servicing crew, aircraft-like operations, and the rapid, low-cost development NASA sought. The average time for preflight maintenance has been demonstrated at 3.5 hours, and 2.5 hours for postflight using a five-person crew (Gaubatz et al, 1993: 2, 7). Total ground crew averaged 15 persons versus the 20-40 estimated (Gaubatz, undated-b: 5). The goal for refueling once hooked up is 20 minutes, with a total refueling time of one hour (Rozycki et al, 1993: 1, 3). In practice, the DC-XA averaged 33 minutes (MDA, 1996e: 1-4). Eight test flights and 18 ground tests were completed in two years. An explosion on flight 6 of 8 forced a successful emergency autoland on the desert floor (Gaubatz, 1995: 3-5). The rapid advancement of flight control software during testing of DC-X has removed further development from the critical path of SSTO progress (Gaubatz et al, 1993: 14). Two flights in one day and a six day turnaround were both successfully demonstrated (Gaubatz, undated-a: 4).

Ground support equipment for the DC-X/DC-XA included a towed launch-to-landing-transporter (LTLT) to move the test vehicle to and from the land/recovery pad. The tow vehicle was a Coleman MB-4 aircraft tug. The LTLT can be operated safely by an Air Force 5-7 level technician, and requires only routine vehicle maintenance. The LTLT concept would probably apply to the full scale vehicle since the RLV cannot be

towed directly while standing on its landing gear. The same tow vehicle can move the portable combination aircraft shelter/depot maintenance hangar. Total weight of the shelter is 41,000 kg (BMDO, 1993). The shelter also contains air conditioning and an overhead crane (Rozycki et al, 1993: 1). See Figure 6 below for ground support layout.

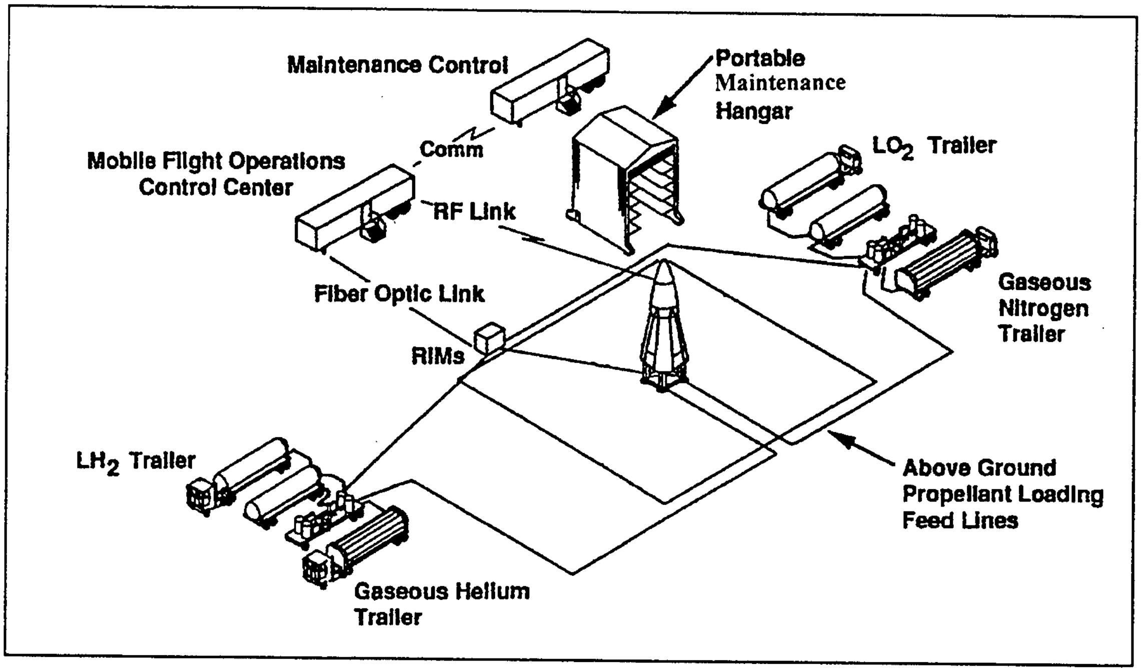

Figure 6. SSTO Ground Support (Gaubatz, undated-a: 5)

One problem has developed in testing the DC-X and DC-XA with regard to the takeoff and landing pad surface. When takeoff and landing on concrete, the surface tends to reflect a great amount of heat back onto the vehicle. Also, the surface of the pad tends to be somewhat melted and/or abraded by the blast. While the heating protection problem seems to be understood and compensated for by a variety of shielding methods, the same cannot be said for protection of the landing/launch pad. When landing on softer surfaces (prepared and unprepared gypsum) the vehicles suffers significantly less heat,

but the engine blast digs large holes in the turf. The holes present a hazard for the landing gear, and the potential that the vehicle will fall over. The test teams came up with a vented grate system to land the vehicle on, but it resulted in strange updrafts on the vehicle as it approached touchdown. Further analysis and investigation continue (MDA, 1996a: 4). No cost figures for the vented grate landing pad were available.

The next vehicle in the development series (X-33) will be capable of suborbital flight, and demonstrate the desired mass fraction for an orbital vehicle through its state-of-the-art lightweight construction materials. It will also demonstrate the scaled up operations and maintenance requirements, low cost manufacturing techniques, and thermal protection (Gaubatz, 1995: 5, 7).

Competition for X-33 vehicle was intense. McDonnell Douglas proposed a 2/3 scale version of the DC-X called DC-X2. Lockheed Martin, the eventual winner, proposed their 1/2 scale VentureStar, and Rockwell International proposed a vehicle similar in design to the Space Shuttle (Apodaca and O'Dell, 1996: D1). The VentureStar will be 20.7 meters wide, 19.2 meters tall, have a dry weight of 28,440 kg, a gross takeoff weight of 124,000 kg, and a mass fraction of 0.77 (Cook, 1996b). It will fly as high as 50 miles at Mach 15. They plan 15 flights between March and December 1999 (Leary, 1996: D5).

The cost of X-33 will be significant--$940 million in NASA funds, $220 million from Lockheed Martin and her partners (Leary, 1996: D5). This price is 55 percent

higher than the McDonnell Douglas estimate for their program of $744 million (Tucker and Panciocco, 1993: 4).

VentureStar's aerospike engines are currently being tested. A 10 percent size prototype built by Lockheed was flown in April 1996 on a modified NASA SR-71 Blackbird to test engine performance (Cook, 1996c: WWWeb). Reports indicate the test was successful and development continues on the half-scale version for X-33.

Lockheed Martin has several partners in the X-33 program. Their Skunk Works in Palmdale CA, Rocketdyne (engines), Rohr (thermal protection), Allied Signal, and Sverdrup (ground support equipment) form the commercial side. A variety of NASA and DoD laboratories form the other half of the team (Cook, 1996d: WWWeb).

Summary

The tests of SSTO systems are moving along on time and on budget. The X-plane style development seems to be working well. And each new success brings NASA, DoD, and industry closer to their goal of an operational SSTO RLV. Assuming the VentureStar is successful, and there is no reason it shouldn't since little new technology is involved, an operational SSTO fleet should be available in 2004 or 2005. Whether the final vehicle will be like the Delta Clipper, the VentureStar, the Shuttle, or some other design is still open to question based on the results of development between now and then. However, assuming the goal of a a deployed fleet is reached, it then leads to the question of whether that mode of transportation is worth the price for surfact-to-surface transportation compared to other modes such as aircraft, truck, train, or ship.

V. Findings and Analysis

"I have destroyed the enemy merely by marches." Napoleon, 1805
(Tsouras, 1992: 244)

Overview

There are many costs involved in setting up an operational SSTO system. Since it will be several years before a full scale SSTO, the figures relating to fixed and variable costs are going to be estimates or outright guesses based on other spacecraft or aircraft operations. Nevertheless, the costs of some things like LOX and LH2 are known, as well as the current price DoD charges its customers to use airlift. Unfortunately, the latter prices do not necessarily reflect the true cost of operation. Nevertheless, they will serve as a starting point. Costs or prices used for other modes of transportation were gathered by telephone directly from companies which provide these services. The nominal "package" they were to deliver weighed 27,000 kg, filled 283 cubic meters, and was sub-divided into 360 .9 m cubed boxes weighing roughly 77 kg apiece. The cargo inside was called "machine parts" for cargo cost classification, and was to be shipped 3218 km (2000 miles).

Cost Data

The competing SSTO companies, Lockheed Martin, McDonnell Douglas, and Rockwell estimate the operational version of an SSTO RLV will cost approximately $5-8

billion, and fly 30-40 flights per year. Lockheed Martin foresees a fleet of 3 vehicles to meet NASA needs for space launch (Leary, 1996: D5). McDonnell Douglas, in concert with AFSPACECOM, see a fleet of four as a minimum (AFSPACECOM, 1993b). The BMDO estimates are higher at $9.5 billion, and Aerospace Corporation estimates a similar amount at $9.4 billion (Hovden et al, 1993 and AFSPACECOM, 1993b). If the SSTO must "payback" its development costs, the repayment will cost as much as $9.5 billion for the initial fleet, plus $1.160 billion for X-33, and $67 million for DC-X. For this purpose, all other costs related to SSTO development are considered sunk costs. These other costs would include all previous related research and development on SSTO or RLV related technologies not specifically paid for under DC-X and X-33. The total is $10.727 billion. At 40 flights per year for 20 years, 4 vehicles will log 3200 flights. $10.727 billion/3200 = $3,352,187/flight. At only 30 flights/year the cost is $4,469,583.

Table 2. SSTO Costs Per Flight (AFSPACECOM, 1993b)

Variable Costs Per Flight (million $ FY93)--Based on 30 flights per year		
Processing	2.5	
Fuel	.8	
Parts and Spares	1.1	
Indirect Support	2.8	
TOTAL	$7.2	
Fixed Cost Per Year (million $ FY93)		
Facility/Equipment O&M	12.0	
Program Support	21.7	
Supplies/Materials	8.5	
Sustaining Engineering	4.8	
TOTAL	$47.0	÷ 30 flights = $1.6/flight
GRAND TOTAL	**$8.8**	**/flight** = $7.2 + $1.6

The only operations and maintenance costs found by the author were the BMDO figures based on the McDonnell Douglas concept. See the cost breakdown above in Table 2. Obviously, the most significant factor in both payback and reducing the fixed cost per flight is the number of flights per year. Commercial and military aircraft fly several times per day, probably averaging 300-500 sorties per year. If an SSTO could reach this utilization rate, the payback and fixed cost would approach negligible figures compared to the variable costs. For example, at 300 sorties per year, the payback cost would drop from $3-4 million per flight to less than $500,000, and fixed costs would drop from $1.6 million per flight to only $160,000.

One of the significant issues in SSTO RLV operations is fuel. Fuel like LOX/LH2 is different from conventional aircraft fuels in that they are cryogenic--they are stored at very cold temperatures to keep them liquid (-218 degrees Celsius for LOX and -259 degrees Celsius for LH2) (Goetz, 1987: 9:35, 6:191). Also, 25 percent or more weight of propellant is used in comparison to vehicle weight on SSTOs than on aircraft. See Table 3 below for a comparison of fuel and gross weights, and fuel costs for the C-17, C-141, Delta Clipper, and VentureStar. An oxidizer/fuel ratio of 2.6:1 is assumed from Space Shuttle fuel usage. The data is based on flying half way around the globe (farthest point--approximately 21,000km. If shorter distances were used, the fuel cost for the aircraft would be lower by the appropriate fraction. However, since SSTOs use most of their fuel climbing out of the atmosphere, fuel costs are not significantly reduced for

shorter distances. In addition, while the SSTOs need roughly an hour for the flight, the C-141 or C-17 would need approximately 30 hours of flight time to reach that distance.

Table 3. Fuel/Gross Weight Ratios and Fuel Costs
(Ligon, 1996: 118-9, and Walsh, 1996)

Vehicle	Fuel kg	Gross Wt kg	Ratio	LOX kg	LH2 kg	Fuel Cost $
C-17	81,600	265,400	.31	NA	NA	$47,000
C-141	68,000	146,500	.46	NA	NA	$42,000
Delta Clipper	429,000	590,000	.73	310,000	119,000	$389,000
VentureStar	898,000	1,043,000	.86	649,000	249,000	$813,000

The cost, however, is not the only issue, there is also the volume. Current Air Force installations, with the exception of Vandenburg AFB and other space launch bases, have only limited cryogenic LOX capacity, and no LH2 storage. For instance, McGuire AFB NJ owns 14,190 liter (216 kg) trailers for LOX and 10,303 liter (245 kg) trailers for liquid nitrogen. They have permanent storage capacity for about 52,000 kg of LOX, and order roughly 43,000 kg per month (Peterson et al, 1996). Since each launch of an SSTO will take between 10 and 20 times the present capacity of McGuire AFB, new facilities will have to be created, transportation or pipeline to the launch pad created, sources of supply found, as well as personnel trained in handling cryogenics.

The SSTO costs in Table 4 below are not unlike those of aircraft. As displayed, while the actual costs may differ by a significant amount, the relative percentage of cost distributions are quite alike. The standout differences are the 16 percent higher share of spares and depot maintenance for the SSTOs, and 4 percent higher support equipment costs. Yet, SSTOs had 8 percent lower system training costs, and the 5 percent lower personnel support costs.

Table 4. Military Aircraft vs. SSTO Cost Distribution
(Summarized from Gaubatz and Sponable, 1994: 5)

	Military Aircraft (%)	SSTO (%)
Spares/Depot Maintenance	21	37
Aircraft Maintenance	20	20
Petroleum Products	18	16
System Training	9	1
Preflight/Flight Operations	8	7
Personnel Support	6	1
Facilities	7	6
System Data	4	1
Support Equipment	4	8
Engineering	3	3

How does the SSTO compare with other modes of transportation? A nominal cargo (27,216 kg or 60,000 lbs) and distance (3300 km or 2000 miles) was created, as mentioned earlier, to give a baseline against which to measure the different transportation modes. Different modes required different carriage depending on the size of the typical movement vehicle. By ship, five containers were required, and a minimum rate was charged since the cargo was not more dense than the minimum charged weight per container. Two rail boxcars were needed to carry the same load, as were three 15.8 meter truck trailers, one C-17, one VentureStar, two Delta Clippers, or two C-141s. The time, cost, and cost per kg to haul the 27,000 kg, 283 cubic meter load are listed below in Table 5. The C-17/C-141 costs are the special air mission tariffs charged to non-DoD customers. The commercial rates are those obtained from the indicated industry sources. The Delta Clipper costs include fixed and variable costs taken from Table 2, while the VentureStar costs were estimates from Bob Baumgartner, RLV Program Manager at

Lockheed Martin. They also include fixed and variable costs. No payback costs were included for the SSTOs.

Table 5. Time and Cost By Mode (27,000 kg for 3300 km)
(multiple sources--see below)

Mode	Time(hrs)	Cost	Cost/kg
Ship	125.00	$ 15,230	$ 0.56
Train	50.00	$ 8,110	$ 0.30
Com. Plane	4.35	$ 75,809	$ 2.79
Truck	40.00	$ 14,144	$ 0.52
C-17	5.00	$ 38,530	$ 1.42
C-141	5.00	$ 81,100	$ 2.98
Delta	0.33	$ 8,800,000	$ 323.34
VentureStar	0.33	$ 10,000,000	$ 367.43

Sources:
For C-17/C-141 speeds and rates--non-US Gov't (Office, 1996: 5, 73).
For ships speed (16 kts.) (Begert, 1996).
For ship costs (SeaLand, 1996).
For train and truck speeds (40 and 50 mph) (Pohlen, 1995).
For train cost (Bollinger, 1996).
For commercial plane speed and cost (460 kts) (Jason, 1996).
For truck costs (Chase, 1996).
For Delta Clipper speed and cost (Gaubatz, 1996 and AFSPACECOM, 1993b)
For VentureStar speed and cost (Baumgartner, 1996)

It is important to emphasize that variation in the distance flown for the SSTOs does not significantly (less than ten percent) affect the cost of the flight or the fuel used. This is because the majority of the fuel is consumed taking off (and landing for the delta Clipper), not during the en route portion. This is unlike aircraft, which are very sensitive to range in their costs. That is why aircraft charge by the en route hour for special air missions or charters. Each hour of flight may burn an additional 5-9,000 kg more fuel, costing $1300 to $2600. That is one-quarter or more of the cost charged on a charter

flight. Since the SSTO is coasting for most of its flight, it burns little or no fuel, in comparison, other than takeoff or landing.

The costs are important to the success of SSTO. As mentioned in Chapter 1, many companies are eyeing SSTO RLVs to gain a new competitive edge in their industries in the future. However, the realization of that advantage will hinge on the value of the transportation. As cited by Alvin Toffler, Jiro Tokuyama, senior advisor to the Mitsui Research Institute, performed a fifteen nation study of telecommunications, transportation, and tourism. He reported that Pacific air passenger traffic was going to grow immensely in the next few decades. He estimated that it would take 500-1000 hypersonic aircraft to handle the growing demand for rapid transit (Toffler, 1990:71-72). In their study of space market demand, Andres et al found that there would be a small linear increase in demand as the price per kilogram fell under $4000. They then predicted that between $100 and $1000/kg there would be an exponential growth in demand. See Figure 7 below. Consequently, much will be riding on the success of SSTO RLV testing besides a vehicle for DoD transportation.

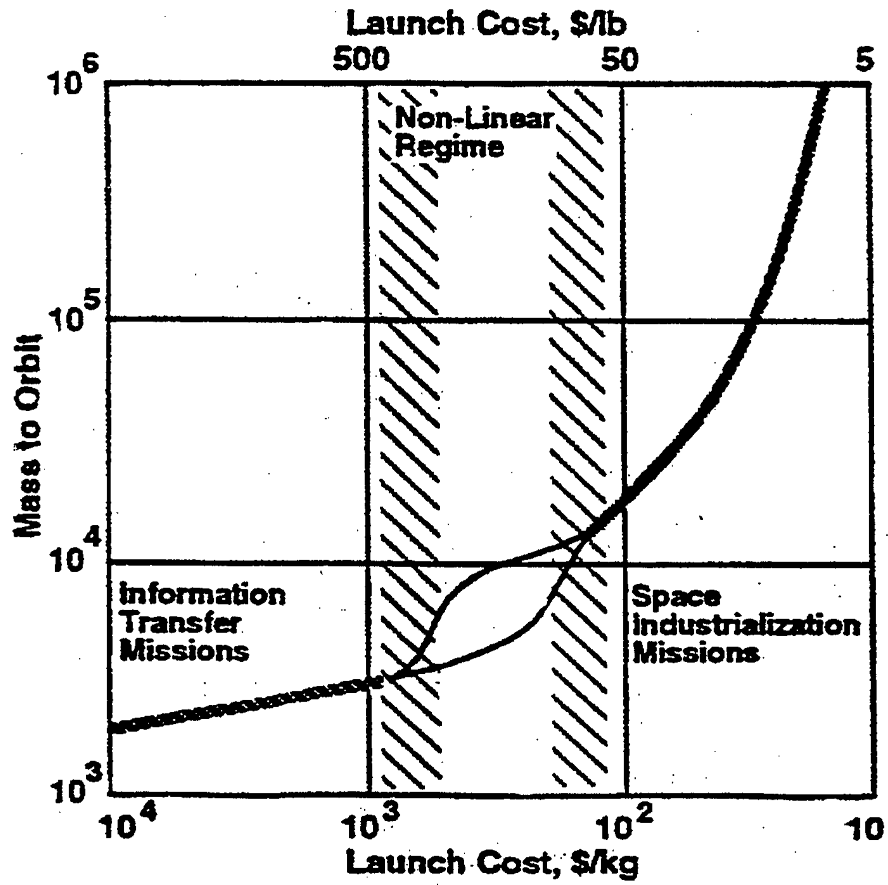

Figure 7. Space Demand Varies With Cost (Gaubatz, 1995: 12)

<u>**Analysis**</u>

Comparing the figures in Table 5 one can attempt to assess the potential value of an SSTO RLV for surface-to-surface transportation. The concept is to use the SSTO costs per kilogram and time to destination as a baseline. Then, for each other mode of transportation, create a ratio with the baseline SSTO numbers. See the results below in Table 6. For the baseline, the Delta Clipper numbers from the AFSPACECOM cost study will be used, with no "payback" amounts added. Ideally, the time ratio and the cost

ratio would be identical, i.e., the shorter delivery time would cost an correspondingly higher amount. All ratio values were rounded for ease of comparison.

Table 6. Transportation Mode Cost and Time Ratios

Mode	Time(hrs)	Time Ratio	Cost/kg	Cost Ratio
Ship	125.00	375:1	$ 0.56	557:1
Train	50.00	150:1	$ 0.30	1078:1
Com. Plane	4.35	13:1	$ 2.79	116:1
Truck	40.00	120:1	$ 0.52	622:1
C-5	5.00	15:1	$ 3.15	103:1
C-141	5.00	15:1	$ 2.98	109:1
Delta	0.33	1:1	$ 323.34	1:1

To read the table, take trains for example. The SSTO is 150 times faster than the train, and 1078 times more costly. Therefore, the train is the better value unless speed is more important than cost. If cost, not time, is the priority, then the lowest cost per kilogram would be the best choice--in this case, train. If speed is the priority and cost does not matter, an SSTO is the best choice. For AMC, comparing the SSTO to aircraft transportation is the key. The SSTO is 15 times faster than typical AMC airlifters, yet costs more than 100 times as much to lift the same load. The aircraft are the better value.

Summary

Does this mean AMC and DoD should not develop or purchase SSTO RLVs? No. However, knowing the relative capabilities of the SSTOs versus aircraft, these organizations can more objectively evaluate the non-quantifiable aspects of RLVs. For

example, AMC flies an average of 1370 missions per week (Begert, 1996). Of those, approximately 450 per week are rated under the JCS Priority system as Priority 1 or 2 (330 Priority 1, 120 Priority 2--usually Special Assignment Airlift Missions and Contingency Missions) (Blanchard, 1996). Could some of those missions rate a higher dollar cost to take advantage of the rapid delivery? What if DESERT EXPRESS had been run by SSTO in DESERT STORM? Under the Defense Business Operating Fund (DBOF), would AMC customers be willing to pay premium rates to have some of their special cargoes and/or passengers delivered in minutes versus hours or days? Cost is obviously not the only driver. However, it is a significant factor in choosing to develop and purchase a weapon system.

V. Conclusions and Recommendations

> *"Our cards were speed and time, not hitting power, and these give us strategical rather than tactical strength. Range is more to strategy than force."*
>
> *Colonel T.E. Lawrence, 1929* (Tsouras, 1992: 434)

Overview

Air Mobility Command must consider future defense transportation needs, even those "outside the box" or paradigm. SSTO RLVs offer new capabilities and technologies to improve old capabilities--namely, rapid transportation. Reusable SSTOs should not be dismissed as spaceships that belong to USSPACECOM or NASA. The suborbital surface-to-surface transportation option offers superior speed and flexibility to modern airlift aircraft. When a shipper can place 11,340 kg of payload or passengers anywhere on the planet in one hour or less, and perhaps land on a parking lot instead of a 3000 meter runway, that is a significant capability.

The use of an SSTO would also comply with and enhance AMC's fulfillment of Global Reach doctrine. Input from the premier DoD operator of air transportation during this development process would lead to a vehicle that meets the peculiar requirements of AMC and its DoD customers. And USSPACECOM is not organized to run surface to surface lift via space--AMC is. While the cost value of SSTO delivery is not in line with aircraft cost value, this does not mean some capability should not be considered. Other tradeoffs may offset the higher operating costs of SSTOs. Lower inventory costs may result due to the capability of an SSTO to provide robust "just-in-time" delivery than

aircraft. In wartime, the difference of delivery times between days, hours, or even minutes may mean a significant difference in the outcome of a battle, a campaign, or even a war. Such benefits may not be reducible to cost comparisons, but they should be considered.

Another consideration may be some sort of cross-subsidization of an SSTO RLV fleet. A joint use arrangement between AMC, AFSPACECOM and NASA could spread the costs, maintenance, and manning required. If a large enough pool of vehicles were purchased, all organizations could use the assets on a prioritized basis (JCS priority with space missions added), yet share the overhead and support costs associated with the new weapons system. As the technology matures and SSTOs become more ubiquitous, AMC could develop its own fleet to meet its needs. In the mean time, the lowered cost of deploying space assets could help offset the higher costs of rapid surface-to-surface transportation. The DBOF payments could also be set to pay a pro rata share of the SSTO operations cost. Air Mobility Command should evaluate these, and other ideas generated by more qualified staff members, to decide how the RLV technology can be used to enhance Global Reach.

Conclusions

SSTO operation is expensive in relation to AMC aircraft. The vehicles also require fuels that the Air Force does not currently handle in large quantity except at space launch bases. However, the RLVs are more flexible in their landing sites, needing only a

137 meters square to land upon. They also offer delivery 15 to 30 times faster than jet aircraft, with comparable payloads. The people at NASA plan to replace the Space Shuttle with the SSTO. Civilian industry is interested in this technology, and plans to exploit it for not only space transportation, but also surface-to-surface transportation over long distances. Ignoring this technology could leave AMC capability far behind the civilian sector, and potentially our future enemies. There are many options AMC can explore in evaluating a full or part share in fielding SSTOs as airlift platforms.

Recommendations

Air Mobility Command and USTRANSCOM should continue to monitor the development of SSTO RLVs for potential use as airlift platforms. While the development costs are fairly high, AMC and USTRANSCOM would not be liable for those costs. Instead, they need only purchase a small fleet (perhaps 4-6) to provide a significant capability, limiting their fuel storage and equipment costs to one location initially. There are also several options, some discussed above, which offer ways for AMC to defray or share the cost of SSTO deployment. As with any new technology, the second generation vehicle would likely be significantly cheaper and more capable. If DoD ignores this capability, the civilian industry will develop the vehicles to suit their needs irrespective of military needs.

Also, AMC should send support and operations specialists to NASA to become actively involved in the development of a system that has the potential to seriously

augment US national airlift capability. The initial interest in SSTOs has been, and will continue to be, from companies interested in space launch. The cost and turnaround advantages over the Space Shuttle are evident from the data presented. It will likely be the second generation of vehicles, or at least several years into regular operation that the surface-to-surface aspect begins to be fully exploited commercially. This is, of course, the area of interest for DoD's transportation specialists. But since such development takes time and expertise, AMC must be involved now. Using the initial SSTO vehicles will provide an unmatched worldwide capability, and should not be ignored on the basis of cost alone.

The experts at AFSPACECOM estimate 36 months from completion of X-33 to completion of the full scale prototype testing, followed by another 24 months to build and test the first four operational SSTOs (AFSPACECOM, 1993b). Since X-33 is scheduled to finish in December 1999, that would make the SSTOs operational at the end of 2004. Since AMC (along with the rest of the Air Force) starts lining up their programs at least seven years out for the budget, consideration in 1996/7 would lead to funding completion in 2004.

Future Research

The SSTO RLVs are currently in test and development. The first flights of the half-scale prototype by Lockheed Martin will be March 1999 with completion in December 1999. The success of those tests should be followed closely. After that,

operational capability is estimated in 2004 or 2005. There is a great amount of specific research that AMC could investigate, and perhaps contribute to the development of a successful AMC SSTO vehicle. Items that could be investigated include creating servicing vehicles that are air transportable, rapid transportation of cryogenic fuels, loading systems for containerized or non-containerized cargo and passengers, building fuel storage facilities, crewed or uncrewed operations studies, creation of an SSTO CRAF, and many more. As costs and operational equipment is refined, more accurate forecasts of budget and material requirements will be known. These must be analyzed and reported for appropriate decision makers to use in developing and purchasing this weapons system. But this research will be done by space operations personnel, no airlifters, if AMC and USTRANSCOM do not get involved now.

Appendix A: Acronyms and Terminology

ATD--Advanced Technology Demonstrator.

BMDO--Ballistic Missile Defense Organization. Air Force successor to SDIO, with primary emphasis on ballistic missile defense, but tasked by Vice President Quayle to pursue SSTO technologies.

DARPA--Defense Advanced Research Projects Agency. Currently managing SSRT programs.

Delta Clipper--The McDonnell Douglas SSTO concept using a VTVL vehicle to launch 11340 kg of payload to LEO. The proposed size is roughly 40 meters tall, 12 meters wide at the base, a cargo volume of 4.6m square by 9.1m long, and a vehicle weight of approximately 47,600 kg. Total liftoff weight with fuel is estimated at 590,000 kg (Ligon, 1996, pp. 119-123).

DC-X--Delta Clipper-Experimental. First prototype of the McDonnell Douglas SSTO RLV--one-third scale. Testing complete 7 July 1995.

DC-XA-- Delta Clipper-Experimental. Revision of first McDonnell Douglas SSTO RLV prototype. Testing complete 31 July 1996.

DoD--Department of Defense.

Dry weight-- the weight of the vehicle less the fuel and cargo.

ELV--Expendable Launch Vehicle. A system, such as a solid booster or rocket that is used and discarded after or during flight. Not reusable.

FOCC--Flight Operations Control Center. The trailer or building where operational control of the launch vehicle is performed. For the Delta Clipper, a minimum crew of three is required.

HLV--Heavy Lift Vehicle. VentureStar, carrying 27,200 kg of cargo, is an HLV.

HTHL--Horizontal Takeoff, Horizontal Landing. The vehicle operates as a typical aircraft. In the case of current SSTO plans, the landing portion is not powered flight, but rather a glider similar to the Space Shuttle's current *modus operandi*. This mode of landing leaves little margin for error during approach, and strictly limits landing destinations.

ILC--Initial Launch Capability.

LH2--Liquid Hydrogen. May only be kept in this state at cryogenic temperatures. Highly flammable.

LN2--Liquid Nitrogen.

LON--Launch On Need. The capability to generate a flight on shorter notice than a typical flight. Lead time varies by craft and preparations.

LOS--Launch On Schedule. Missions launched from a predetermined schedule.

LOX or LO2--Liquid Oxygen. May only be kept in this state at cryogenic temperatures. Flammable.

Low Earth Orbit (LEO)--Typically 300-500 nautical miles above the earth's surface. Many satellites are launched to this region, as opposed to geosynchronous orbit at 22,300 nautical miles. Government requirements for SSTO launch consider 100 nautical miles as LEO.

LRU--Line Replaceable Unit. A system component that is not repaired in place. Rather, that unit, upon failing, is removed and replaced by another similar unit, typically taking little time. LRUs are usually repaired at a depot level repair location rather than the line maintenance facility.

LTLT--Launch-To-Landing-Transporter. A towed vehicle used to move the DC-X/DC-XA to and from the launch pad.

Margin--the weight growth allowance used in initial feasibility studies of spacecraft by engineers. These "pessimistic" numbers allow for growth in the weight of system components or inefficiencies in propulsion. Any unused margin left in an operational system results in a performance increase, though the entire system is structurally limited to carrying that maximum load. Unused margin will allow payloads to be lifted to a higher orbit than originally planned, or increased robustness and operational flexibility (Bekey, 1994). It does not, unfortunately, allow for more cargo mass since the structure was not designed to carry more. A 15% margin is typical.

Mass Fraction-- the propellant weight divided by vehicle gross weight less the payload. An ideal vehicle would have a mass fraction of 1.0. This is unattainable since the vehicle would then be weightless, massing only the fuel and cargo. However, it is a good indicator of how close a given system comes to the ideal (Bekey, 1994) As a reference, an SSTO vehicle built with Space Shuttle engines must have a mass fraction exceeding

0.92 to reach low earth orbit. Current Shuttle technology gives only 0.84. More efficient propulsion and/or lighter dry weight mean you can get a higher attainable mass fraction.

MAV--Military Aerospace Vehicle.

MLV--Medium launch Vehicle. The Delta Clipper is in this class at 11,340 kg of payload. The VentureStar, with 27,200 kg of payload would be a Heavy Lift Vehicle.

MSFC--Marshall Space Flight Center. Located in Alabama, and center for NASA SSTO development.

NASA--National Aeronautics and Space Administration. The lead national agency for most space related issues in the US.

NASP--National Aerospace Plane. A defunct program from the 1980s with the goal of creating an airbreathing hypersonic aerospace craft.

Payload Fraction--payload weight divided by total vehicle weight (fuel, cargo, and vehicle). The higher the payload fraction, the better the performance since the vehicle is moving more payload as a fraction of the total mass. Again, 1.0 would be the ideal payload fraction as the entire vehicle would be payload. The Space Shuttle currently has a payload fraction of .7 percent (seven-tenths of one percent). By comparison, most cargo aircraft have a 20-25 percent payload fraction. The Delta Clipper is planned to have about a 1.5 percent payload fraction (Ligon, 1996, p. 119).

RLV--Reusable launch vehicle. The space craft needs no major servicing or overhaul between flights--similar to aircraft operations.

SDIO--Strategic Defense Initiative Organization. Air Force organization responsible for developing President Reagan's Star Wars program and related space technologies.

SLS--Space Launch System. The national space launch sites and associated capability.

Space Shuttle--Current surface to LEO launch system for the US. The Shuttle itself weighs approximately 160,000 ponds, lifts a payload of about 14,500 kg, and relies on three additional boosters that make the total takeoff weight nearly 2041 metric tons. The shuttle requires 9-15,000 people working roughly six months to prepare for a launch, which costs approximately $500 million (Ligon, 1996, p. 122).

Specific Impulse (I_{sp})--a measure of propulsion efficiency, it is the amount of thrust produced per pound of propellant. The specific impulse of a propulsion system (fuel/engine) is measured in seconds, and has a direct impact on the mass fraction attained by a launch vehicle. Specific impulse differs from thrust in that you can have

high thrust and low specific impulse or other combinations. An analogy would be the powerful, gas guzzling car that can burn rubber but only gets 3 km per liter. The propulsion system must provide enough thrust to get airborne, but also be efficient to reduce the amount of propellant required. Generally, higher specific impulse means a better propulsion system. As a reference, the Shuttle (with solid boosters attached) provides about 460 seconds I_{sp}, while the final Delta Clipper is estimated at 450 seconds (Ligon, 1996, p. 119). Nitroglycerin yields about 200 seconds.

SSME--Space Shuttle Main Engine

SSRT--Single Stage Rocket Technology. The overall program title for SSTO development by the US government.

SSTO--Single Stage To Orbit. The vehicle does not shed any parts or stages during the flight. All parts stay connected throughout the mission.

STS--Space Transportation System. The national capability to transport items to and from space.

VTVL--Vertical Takeoff, Vertical Landing. The vehicle launches from an upright position like a typical rocket. Upon return to the surface, the vehicle turns around to place its tail toward the ground, typically using its engine thrust as a brake against gravity. It then lands upon its tail or extended landing gear. This powered landing allows for greater flexibility of landing destinations during the descent phase, and allows for easier glidepath corrections--including the ability to hover.

VentureStar--Lockheed Martin Phase II prototype of their SSTO RLV concept. The craft will be roughly half-scale, and fly up to mach 15 at suborbital altitudes. The cost of the program is approximately $1 billion--done as a cost share between NASA and industry. The NASA name for this project is X-33.

X-33--The NASA name for Phase II of the SSTO RLV development project. The contract was won by the Lockheed Martin corporation and their allied subcontractors.

X-34--A terminated program that intended to provide another step in the development of SSTO between DC-XA and X-33. The program was to be another cost share program, with $100 million from industry and $70 million from NASA. The program was dropped after industry voiced their concern that the cost was not worth the gains (Ames, 1996, WWWeb).

Additional acronyms may be found in the Acronym Dictionary (Third Edition, January 1996), published by the USAF Air Mobility Warfare Center (AMWC), Ft Dix, NJ. The OPR is HQ AMWC/WCOMO.

Appendix B: Points of Contact

Launchspace. This company offers space science courses and seminars to individuals or corporations to educate them on broad or specific details of technology or space systems. Scheduled events are year round, but can be tailored to a specific customer. They are sponsotred by the Untied States Space Foundation. Launchspace 7235 1/2 Arlington Boulevard, Falls Church VA 22042, or 1-800-553-5907, Fax (703) 698-0211.

Lockheed Martin, RLV Program Manager, Bob Baumgartner. He can be reached at (805) 572-6192.

McDonnell Douglas, SSTO Program Manager, Dr. William Gaubatz, Deputy Program Manager for DC-X, Paul Klevatt, or Chief Engineer for DC-XA, D.A. Steinmeyer. McDonnell Douglas Aerospace, 5301 Bolsa Chica Avenue, Huntington Beach, CA 92647-2099, or (714) 896-3311.

McDonnell Douglas, supportability and maintainability issues, Ray Smiljanic, (310) 593-4958.

NASA Marshall Space Flight Center, Deputy Program Manager for X-33, Steve Cook. He can provide significant information on NASA involvement in SSTO development. His phone number is (205) 544-4918.

USAF, Advanced Spacelift Technologies, Lt Col Jess M. Sponable. Lt Col Sponable was the Air Force Program Manager for BMDO during the DC-X tests. PL/VT-X, 3550 Aberdeen Aveneue SE, Kirtland AFB NM 87117, or phone (505) 846-8927/5929, ext. 127, or sponablj@plk.af.mil.

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Vita

Major John R. Stafford was born on 14 December 1960 in Los Angeles, California. He graduated with honors from Loyola High School in 1979 and entered the Air Force Academy. He was commissioned and graduated with a Bachelor of Science degree in Engineering and a minor in Military History in June 1983.

His first assignment was to Williams AFB where he completed Undergraduate Pilot Training in July 1984. His next assignment was to Norton AFB where he flew the C-141B, upgrading to instructor and specializing in airdrop and air refueling missions. In January 1989 he moved to Altus AFB as a schoolhouse instructor, flight examiner, and Chief of C-141 Training Programs. While at Altus AFB, he earned a Master of Arts degree in Social Science from Syracuse University. Next, Maj Stafford was assigned to HQ AMC in 1992, where he worked as the Deputy Chief of Protocol and later the Command C-141 Chief Pilot in Aircrew Standardization. In July 1995, he entered the Advanced Study of Air Mobility Master's Degree Program at the Air Mobility Warfare Center, sponsored by the School of Logistics and Acquisition Management, Air Force Institute of Technology. His follow-on assignment is to HQ USAF/XOXS, the "Skunk Works." Maj Stafford is a graduate of Squadron Officers School and Air Command and Staff College.

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13. ABSTRACT *(Maximum 200 Words)*

The US military must think creatively to exploit potentially useful developing technologies in the pursuit of national security. Single Stage to Orbit (SSTO) Reusable Launch Vehicles (RLVs) are currently under cooperative development by NASA, the Air Force, and the aerospace industry in the pursuit of assured commercial and national access to space. The transportation elements of DoD (Air Mobility Command and USTRANSCOM) have the opportunity to exploit these rapid transit technologies to advance "Global Reach for America." The SSTO RLV is a single stage rocket that will be completely reusable, similar to an aircraft, yet deliver a C-130 size cargo anywhere on the planet in less than one hour. Industry, Air Force, and NASA sources were investigated to assess the projected capabilities and costs of the SSTO system.

This paper reviews the proposed capabilites of the SSTO system, discusses the current status of the development and test program, compares the proposed capabilities with current DoD and commercial transportation modes and costs, and recommends that Air Mobility Command, as airlift agent for USTRANSCOM and DoD as a whole, should pursue development and limited acquisition of SSTO RLVs for use as airlift platforms.

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